IFDEPS

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IFDEPS Virtual Thursdays 2021

International Forum on Detectors for Photon Science

March 25th, April 1st and 8th

Event Booklet

Final version: April 8, 2021

Contents

IFDEPS Organisers:

- Gabriella Carini (Brookhaven National Laboratory)
- Takaki Hatsui (RIKEN SPring-8 Center)
- Pablo Fajardo (ESRF - The European Synchrotron)

Technical support

- Kimberley Robert (ESRF)
- Takashi Kameshima (SACLA)
- Toshiyuki Nishiyama Hiraki (SACLA)
- Yoshiaki Honjo (SACLA)
- Kyo Nakajima (SACLA)

Final version: April 8, 2021

IFDEPS Virtual Thursdays 2021 — *PROGRAMME OVERVIEW*

Starting local time

West (PDT)	6 a.m.		North America
Central Standard (CST)	7 a.m.		North America
Central Daylight (CDT)	8 a.m.		North America
East (EDT)	9 a.m.		North America
	10 a.m.		Brazil
	1 p.m.	2 p.m.	UK
	2 p.m.	3 p.m.	Europe
	9 p.m.		China, Taiwan
	10 p.m.		Japan, Korea
	12 p.m.	11 p.m.	East Australia

Thursday, March 25th

00:00	***Welcome to IFDEPS VT***
+0:10	*Session 1* **Facility overview I** *APS - A. Miceli* *CHESS - K. Shanks* *DESY - H. Graafsma* *DLS - N. Tartoni* *ELETTRA - R. Menk* *ESRF - T. Martin* *EuXFEL - M. Turcato* *LCLS - M. McKelvey* *LNLS - J. Polli*
+1:40	*Break*
+1:50	*Session 2* **Facility overview II** *MAX IV - P. Bell* *NSRRC - Y. Huang* *PAL-XFEL - H. Hyun* *PSI - B. Schmitt* *SACLA - T. Hatsui* *SHINE - Z. Liu* *SPring-8 - Y. Imai* *SOLEIL - F. Orsini*
+3:10	***Thursday wrap-up***

Thursday, April 1st

00:00	***Thursday opening***
+0:05	*Session 3* **Deployment and application I** *M. Ramilli* *J. Sztuk-Dambietz* *M. Cascella* *A. Dawiec*
+0:45	*Session 4* **New detector projects** **charge integration** *S. Stern* *A. Marras* *J. Zhang* *P. Busca*
+1:25	*Break*
+1:35	*Session 5* **Readout, DAQ and online processing** *Z. Matej* *T. Hiraki* *N. Janvier* *R. Nishimura* ~~*D. Gorni*~~
+2:25	*Session 6* **Energy dispersive detection** *S.-J. Lee* *G. Oneil* *F.J. Iguaz* *G. Dennis*
+3:05	***Thursday wrap-up***

Thursday, April 8th

00:00	***Thursday opening***
+0:05	*Session 7* **Deployment and application II** *M. Porro* *K. Setoodehnia* *C. B. Wunderer* *A. Mozzanica*
+0:45	*Session 8* **New detector projects** **indirect detection** *T. Kameshima* *T. Lee*
+1:05	*Session 9* **New detector projects** **photon counting** *A. Bergamaschi* *J. Correa / D. Pennicard* *D. Magalhães*
+1:35	*Break*
+1:45	*Session 10* **Sensors, components and technology** *H. Hyun* *A. Tremsin* *A. Tyazhev* *A. Rumaiz* *K. Pauwels*
+2:35	*Session 11* **Advanced silicon sensors** *G. Pinaroli* *T. Hemperek* *H. Park* *G. Giacomini*
+3:10	***IFDEPS VT closure***

Facility correspondents and number of participants

Lab/ Facility	Country	Lab Correspondent	Number of participants
America			
APS - Advanced Photon Source (ANL)	USA	Antonino Miceli	1
ALS - Advanced Light Source (LBNL)	USA	Anton Tremsin	1
CHESS - Cornell High Energy Synchrotron Source	USA	Kate Sato Shanks	1
CLS - Canadian Light Source	Canada	Tom Regier	4
LCLS - Linear Coherent Light Source	USA	Mark McKelvey	5
LNLS - Brazilian Synchrotron Light Laboratory	Brazil	Jean Polli	4
NSLS-II - National Synchrotron Light Source (BNL)	USA	Peter Siddons	10
SSRL - Stanford Synchrotron Radiation Lightsource	USA	Jun-Sik Lee	3
Asia Pacific			
Australian Synchrotron (ANSTO)	Australia	Chris Hall	1
HEPS - High Energy Photon Source (IHEP)	China	Wei Wei	2
NSRRC - National Synchrotron Radiation Research Cent	Taiwan	Yu-Shan Huang	7
PAL-XFEL - Pohang Accelerator Laboratory	South Korea	Intae Eom	7
Photon Factory (KEK)	Japan	Shunji Kishimoto	3
SACLA - SPring-8 Angstrom Compact free electron Lase	Japan	Takaki Hatsui	11
SHINE - Shanghai XFEL	China	Zhi Liu	12
SPring-8 - Super Photon Ring 8 GeV	Japan	Yasuhiko Imai	7
Europe			
ALBA Synchrotron	Spain	Oscar Matilla	9
DESY - Deutsches Elektronen-SYnchrotron	Germany	Heinz Graafsma	14
DLS - Diamond Light Source	UK	Nicola Tartoni	11
ELETTRA Sincrotrone Trieste	Italy	Ralf Menk	2
European XFEL	Germany	Steve Aplin	16
ESRF - The European Synchrotron	France	Pablo Fajardo	15
MAX IV Laboratory	Sweden	Paul Bell	9
PSI - Paul Scherrer Institut	Switzerland	Bernd Schmitt	6
Synchrotron SOLEIL	France	Fabienne Orsini	4
		Total	**165**

Participation per affiliation country

Country	Number of participants
Australia	1
Brazil	4
Canada	4
China	15
France	19
Germany	29
India	1
Italy	1
Japan	20
Russia	1
South Korea	7
Spain	9
Sweden	8
Switzerland	6
Taiwan	8
UK	11
USA	21
	165

List of participants

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Bergamaschi, Anna	Paul Scherrer Institut, Switzerland
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Sztuk-Dambietz, Jolanta	European XFEL GmbH, Germany

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Uruga, Tomoya	JASRI, Japan
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Weninger, Clemens	Lund University, Sweden
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Wollesen, Laura	ESRF, France
Woods, Russell	Lund University, Sweden
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Wunderer, Cornelia	DESY, Germany
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Yin, Ping Yeh	National Synchrotron Radiation Research Center, Taiwan
Yousef, Hazem	European XFEL GmbH, Germany
Yu, Kuanli	National Synchrotron Radiation Research Center, Taiwan
Zhang, Jiaguo	Paul Scherrer Institut, Switzerland
Zhu, Ruixue	ShanghaiTech University, China

Facility overview reports

Session 1

APS - Advanced Photon Source (ANL), *Antonino Miceli*

CHESS - Cornell High Energy Synchrotron Source, *Katherine Shanks*

DESY - Deutsches Elektronen-Synchrotron, *Heinz Graafsma*

DLS - Diamond Light Source, *Nicola Tartoni*

ELETTRA Sincrotrone Trieste, *Ralf Menk*

ESRF - The European Synchrotron, *Thierry Martin*

European XFEL, *Monica Turcato*

LCLS - Linear Coherent Light Source, *Mark McKelvey*

LNLS - Brazilian Synchrotron Light Laboratory, *Jean Polli*

Session 2

MAX IV Laboratory, *Paul Bell*

NSRRC - National Synchrotron Radiation Research Center, *Yu-Shan Huang*

PAL-XFEL - Pohang Accelerator Laboratory, *HyoJung Hyun*

PSI - Paul Scherrer Institut, *Bernd Schmitt*

SACLA - SPring-8 Angstrom Compact free electron Laser, *Takaki Hatsui*

SHINE - Shanghai XFEL, *Zhi Liu*

SPring-8 - Super Photon Ring 8 GeV, *Yasuhiko Imai*

Synchrotron SOLEIL, *Fabienne Orsini*

Flash talks

Session 3 – Deployment and application I

M. Ramili, *The JUNGFRAU and GOTTHARD-II detectors at European XFEL: status and plans*

J. Sztuk-Dambietz, *1 Mpix Adaptive Gain Integrating Pixel Detector (AGIPD) at European XFEL – Experience with the detectors installed at SPB/SFX and MID Instruments*

M. Cascella, *Gain calibration of the AGIPD detector using low intensity X-ray data*

A. Dawiec, *Characterization of the XSPA-500k photon counting detector at Synchrotron SOLEIL*

Discussion moderator: Fabienne Orsini

Session 4 – New detector projects: charge integration

S. Stern, *The new AGIPD detector generation*

A. Marras, Development of CoRDIA: a detector for diffraction-limited SRs and CW FELs

J. Zhang, The high speed microstrip detector Gotthard-II: Architecture, features and applications

P. Busca, XIDER: a novel X-ray detector for the next generation of high-energy synchrotron radiation sources

Discussion moderator: Katherine Shanks

Session 5 – Readout, DAQ and online processing

Z. Matej, *Azimuthal integration for fast X-ray area detectors on FPGAs*

T. Hiraki, *Development of data acquisition and analysis infrastructure for high-speed X-ray imaging detector CITIUS*

N. Janvier, *RASHPA: a generic RDMA-based distributed DAQ framework for high-throughput X-ray detectors*

R. Nishimura, *Development status of new readout system for SOI pixel detector using 10 Gb Ethernet SiTCP*

~~D. S. Gorni, *Event driven readout system with non-priority arbitration for radiation detectors*~~ PRESENTATION WITHDRAWN

Discussion moderator: Nicola Tartoni

Session 6 – Energy dispersive detection

S. Lee, *Application of TES spectrometers in advanced x-ray spectroscopy at SSRL*

G. O'Neil, *Soft X-ray transition edge sensor spectrometers at SSRL*

F.J. Iguaz, *Simulation of the signal response of x-ray spectroscopy detectors*

G. Dennis, *(Very) quick EXAFS using the timestamp capabilities of Xspress4 DPP at Diamond Light Source*

Discussion moderator: Peter Siddons

Session 7 – Deployment and application II

M. Porro, *The DSSC soft X-ray camera with Mega-frame readout capability for the European XFEL*

K. Setoodehnia, *Calibration of a pnCCD detector at European XFEL*

C. Wunderer, *The Percival 2-Megapixel soft X-ray system in first user experiments*

A. Mozzanica, *The JUNGFRAU as imaging detector for SwissFEL low energy beamline*

Discussion moderator: Ralf Menk

Session 8 – New detector projects: indirect detection

T. Kameshima, *Development of a 200-nm-resolution X-ray imaging detector with a field of view of 2 mm square*

Te-Hui Lee, *CMOS X-ray Strip Detector Development at NSRRC*

Discussion moderator: Thierry Martin

Session 9 – New detector projects: photon counting

A. Bergamaschi, *MYTHEN III: the new microstrip detector for powder diffraction*

J. Correa / D. Pennicard, *TimePix4, a versatile timestamping pixel detector*

D. Magalhães, *SPHIRD: small pixel, high rate photon counting detector for synchrotron applications*

Discussion moderator: Heinz Graafsma

Session 10 – Sensors, components and technology

H. Hyun, *Development of thermoelectric cooling system for the PERCIVAL detector*

A.S. Tremsin , *Fast MCP/Timepix photon counting detectors with high spatial and timing resolution*

A. Tyazhev, *Investigation of HR GaAs:Cr material and X-ray pad sensors made of VGF n-GaAs wafers*

A. Rumaiz, *High-Z detectors for photon science*

K. Pauwels, *Structured scintillators review*

Discussion moderator: Anna Bergamaschi

Session 11 – Advanced silicon sensors

G Pinaroli, *Large-area, highly granular detectors for hard X-rays*

T. Hemperek, *Large area silicon sensors in advanced CMOS process*

H. Park, *Switch performance measurement of junction field effect transistor integrated in pixel sensor*

G. Giacomini, *Low-gain avalanche diodes for photon science*

Discussion moderator: Mark McKelvey

Flash talk abstracts

The JUNGFRAU and GOTTHARD-II detectors at European XFEL: status and plans

M. Ramilli[1] on behalf of the European XFEL Detector Operation Group[1] , A. Mozzanica[2], J. Zhang[2] and B. Schmitt[2]

[1] European XFEL GmbH , Holzkoppel 4, 22869 Schenefeld, Germany
[2] Paul Scherrer Institut, Forschungsstrasse 111, 5232 Villigen, Switzerland

Abstract:

The European X-ray Free Electron Laser is the world's most brilliant X-ray free-electron laser delivering of up to 27.000 ultrashort (< 100 fs) spatially coherent X-ray pulses in the energy range between 0.25 and 20 keV, organized in 10 equidistant X-ray pulse trains per second [1]. Consequently, performance requirements for detectors to be employed include a wide dynamic range, able to cover four orders of magnitude in intensity, and the possibility of coping with the 4.5 MHz pulse repetition rate: for this reason, the JUNGFRAU and GOTTHARD-II detectors developed at the Paul Scherrer Instiut in Switzerland are used extensively at European XFEL.

JUNGFRAU is an established charge integrating hybrid pixel detector with dynamic gain switching, developed for XFEL and synchrotron applications [2]. Despite not being designed to operate at the MHz-level pulse rate of the facility, thanks to its wide dynamic range it is nonetheless widely employed at EuXFEL, with a total of 17 modules installed at various scientific instruments. Its operation and its main results will be summarized, and the challenges in pushing the limit of the technology will be highlighted, especially concerning its frame rate capabilities.

On the other hand, the GOTTHARD-II strip detector, also with dynamic gain switching, charge integrating architecture, has been explicitly designed to fully exploit the 4.5 MHz EuXFEL pulse rate[3]; this feature will make it the most widely employed device for spectroscopy in the facility, with a total of 29 modules that will be installed in scientific instruments and beam diagnostic setups. The development is currently in its final stage, and the facility is preparing for the integration of this new detector technology: the steps towards full operation will be highlighted, with particular attention to the challenges posed by this specific device.

[1] M. Altarelli et al., *European X-ray Free Electron Laser*, Technical Design Report, ISBN 978-3-935702-17-1 (2006).

[2] A. Mozzanica et al., *The JUNGFRAU detector for applications at synchrotron light sources and XFELs*, Synchrotron Radiation News, 31(6), 16-20 (2018).

[3] J. Zhang et al., *Towards Gotthard-II: development of a silicon microstrip detector for the European X-ray Free-Electron Laser*, Journal of Synchrotron Radiation, 25(6): 1753-1759 (2018).

1 Mpix Adaptive Gain Integrating Pixel Detector (AGIPD) at European XFEL – Experience with the detectors installed at SPB/SFX and MID Instruments

Jolanta Sztuk-Dambietz[1] for the European XFEL Detector Operation Group[1],
SPB/SFX Instrument Group[1], MID Instrument Group[1] and the AGIPD Consortium[2]

[1] European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany
[2] Deutsches Elektronen-Synchrotron, Paul Scherrer Institut, University of Hamburg, University of Bonn

Abstract:

The European X-ray Free Electron Laser (XFEL.EU) is the world's most brilliant X-ray free-electron laser delivering of up to 27.000 ultrashort (< 100 fs) spatially coherent X-ray pulses in the energy range between 0.25 and 20 keV, organized in 10 equidistant X-ray pulse trains per second [1]. The large variety of scientific applications at the XFEL.EU require different instrumentation, in particular different 2D imaging detectors which can cope with high repetition rate of 4.5 MHz. The facility went into its operation phase on July 1, 2017.

The 1 Megapixel AGIPD detectors [2] developed by the AGIPD Consortium are the primary detectors used for User Experiments at the SPB/SFX [3] and MID [4] instruments. The SFX/SPB AGIPD detector is installed since the start of operation in 2017, while the MID AGIPD followed in November 2018.

The detector consists of a hybrid pixel array with readout ASICs bump-bonded to a silicon sensor with a pixel size of 200 µm × 200 µm. The ASIC is designed in 130 nm CMOS technology and implements a gain switching technology providing a high dynamic range of 10^4 photons. The ASIC internal analogue memory can store at the maximum 352 pulse resolved images. The images are subsequently read out and digitized during the 99.4 ms break between the XFEL X-ray pulse trains.

I will report about the experience gained with operation of the AGIPD detectors at the SPB/SFX and MID instruments. I will also provide a short summary regarding the ongoing updates and improvement activities.

[1] M. Altarelli et al., *European X-ray Free Electron Laser*, Technical Design Report, ISBN 978-3-935702-17-1 (2006).

[2] A. Allahgholi et al., *The Adaptive Gain Integrating Pixel Detector at the European XFEL*, Journal of Synchrotron Radiation, 26:74–82, (2019).

[3] A. P. Mancuso et al. ,*The Single Particles, Clusters and Biomolecules and Serial Femtosecond Crystallography Instrument of the European XFEL: Initial installation*, Journal of Synchrotron Radiation, 26(3):660–676, (2019).

[4] Madsen, A. et al., *Technical Design Report: Scientific Instrument MID*, European XFEL GmbH, Technical Report 2013-005 (2013).

Gain calibration of the AGIPD detector using low intensity X-ray data

M. Cascella[1] for the European XFEL Detector Operation Group[1], SPB/SFX Instrument Group[1], MID Instrument Group[1] and the AGIPD Consortium[2]

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[2] Deutsches Elektronen-Synchrotron, Paul Scherrer Institut, University of Hamburg, University of Bonn

Abstract:

Precise calibration of the gain for each pixel of an imaging detector is essential to its performance. Calibration using a physical signal is essential in order to establish the absolute gain scale and provide a baseline for the charge injection system.

AGIPD is a hybrid pixel X-ray detector with 352 analog memory cells [2] designed to exploit the EuXFEL (European XFEL) MHz-pulsed beam structure[1]. To establish the gain calibration for each of the detector pixel and memory cell we acquired low intensity (~1γ/pixel/pulse) Cu fluorescence flat field data at the EuXFEL's SPB/SFX and MID instruments [3, 4]. After correcting for the offset and common mode noise, we produced a signal spectrum for each pixel and cell. Finally we established a robust, fully automatic, heavily parallelisable procedure, integrated in the EuXFEL offline calibration pipeline, to fit the noise peak and the 1, 2, 3 photons peaks for each of the 352M spectra where the peak distance is used to measure the gain for each channel.

The procedure provides a reliable absolute gain calibration for AGIPD with a very high efficiency (98.4% for SPB's detector). To assess the quality of the resulting gain map we applied it to the original Cu flat field data and used measurements of image smoothness and the integrated photon spectrum to quantify the improvement over the uncorrected data. The peak resolution is improved by up to 20% and the median discrete Laplace filter by ~25%.

[1] A. Allahgholi et al., *The Adaptive Gain Integrating Pixel Detector at the European XFEL*, Journal of Synchrotron Radiation, 26:74–82, (2019).

[2] M. Altarelli et al., *European X-ray Free Electron Laser*, Technical Design Report, ISBN 978-3-935702-17-1 (2006).

[3] A. P. Mancuso et al., *The Single Particles, Clusters and Biomolecules and Serial Femtosecond Crystallography Instrument of the European XFEL: Initial installation*, Journal of Synchrotron Radiation, 26(3):660–676, (2019).

[4] Madsen, A. et al., *Technical Design Report: Scientific Instrument MID*, European XFEL GmbH, Technical Report 2013-005 (2013).

Characterization of the XSPA-500k photon counting detector at Synchrotron SOLEIL

A. Dawiec[1], F. Orsini[1], Y. Nakaye[2], T. Sakumura[2], Y. Sakuma[2], S. Mikusu[2], T. Taguchi[2], J. D. Ferrara[3], P. Grybos[4], R. Szczygiel[4] and P. Maj[4]

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[2] Rigaku Corporation, 3-9-12 Matsubara-cho, Akishima-shi, Tokyo 196-8666, Japan
[3] Rigaku Americas Corporation, 9009 New Trails Drive, The Woodlands, TX 77381, USA
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Abstract:

The XSPA-500k is an X-ray hybrid pixel array detector based on the UFXC32k single photon counting readout chips that has been recently developed and commercialized by Rigaku Corporation [1]. The detector poses several unique and attractive features such as: a large and seamless array of 76 µm square pixels, a very high-count rate, two energy thresholds and ultra-short gate operation. In this work we present the first exhaustive and quantitative characterization and performance evaluation of the XSPA-500k detector using synchrotron radiation that has been done at Synchrotron SOLEIL together by the SOLEIL Detector Group, AGH-UST and Rigaku. The main figures of merit of the detector such as sensor homogeneity, noise power spectrum, detective quantum efficiency and linearity have been measured and will be presented. Additionally, the ability of the detector to operate with an ultra-short gate and therefore to perform pump-probe time resolved experiments, without need to use an external shutter, has been experimentally evaluated and confirmed.

[1] Y. Nakaye et al., *Characterization and performance evaluation of the XSPA-500k detector using synchrotron radiation*, J. Synchrotron Radiat., vol. 28, no. 2, pp. 1–9, 2021.

The new AGIPD detector generation

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Abstract:

The Adaptive-Gain Integrating Pixel Detector (AGIPD)[1], a megahertz frame-rate, high-dynamic range integrating pixel detector, was developed for photon science experiments at the European X-Ray Free Electron Laser (European XFEL)[2]. Since 2017, two 1-Megapixel AGIPD detector systems have been installed at the European XFEL producing numerous scientific results and publications.

In order to further improve the existing AGIPD detector systems, and to reach out into new areas, we have been developing the next generation of AGIPD hardware. Two new generation of ASICs have been developed: AGIPD1.2 corrects a problem with the gain encoding in AGIPD1.1, effectively improving the useful dynamic range of the system. The other generation, AGIPD1.3, is an electron collecting version of the ASIC, needed for readout of high-Z sensor materials such as Gallium-Arsenide (GaAs), Cadmium-Telluride (CdTe), or Cadmium-Zinc-Telluride (CdZnTe). Such sensors are needed to provide higher absorption efficiencies for photon energies in the range from 15-30 keV, which are demanded by a number of user communities. On the backend, new, more compact, read-out electronics have been developed most notably including a new FPGA, firmware, and all-optical communication with new multifibre Gbit transceivers.

A 0.5-Megapixel prototype system with new readout electronics and AGIPD1.2 ASICs has been commissioned and operated in user experiments at the HED (high-energy density) instrument in 2020. Furthermore, we are building two new detector systems including this new hardware, a 4-Megapixel system for the SFX user consortium at the SPB/SFX instrument, and a 1-Megapixel with high-Z sensors for the HIBEF user consortium at the HED instrument. In addition, also the existing AGIPD detectors at SPB and MID will be equipped with new front-end modules containing AGIPD1.2.

We will present and discuss the current status of these new developments and show experimental results from the second generation prototype AGIPD system at HED.

[1] A. Allahgholi et al., *The Adaptive Gain Integrating Pixel Detector at the European XFEL*, J. Synchrotron Rad. 26 (2019).

[2] M. Altarelli et al., *European X-ray Free Electron Laser*. Technical Design Report, ISBN 978-3-935702-17-1 (2006).

Development of CoRDIA: a detector for diffraction-limited SRs and CW FELs

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Abstract:

Substantial upgrades to X-ray sources are foreseen in the near future, with SRs being upgraded to become diffraction-limited, while highbrilliance FELs shifting from pulsed operation to Continuous Wave (CW) operation. A common need emerges for detectors able to operate continuously at high rates, while having a high dynamic range, and single photon sensitivity. The CoRDIA (COntinuous Readout Digitising Imager Array) detector is being developed as an answer to such needs, in a collaboration between DESY and Bonn University.

The detector will build on the experience of charge-integrating detectors for FEL applications, extending operation to CW mode up to a maximum frame rate of few hundred kHz. On-chip Analog-to-Digital Conversion and a Continuous Writing-Reading scheme are foreseen to allow operation also during detector readout. The ASIC is designed for compatibility with several sensors types to cover different energy ranges. Its goal is to achieve single-photon resolution, while at the same time extending the dynamic range to several thousands of photons by mean of adaptive gain selection.

An exploratory prototype of the readout ASIC in TSMC 65nm technology (to test architectural solutions) is foreseen to be submitted this year.

The high speed microstrip detector Gotthard-II: Architecture, features and applications

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Abstract:

Gotthard-II is a charge-integrating silicon microstrip detector with a pitch of either 50 µm or 25 µm [1]. It is initially developed for experiments at the European X-ray Free-Electron Laser (EuXFEL) [2,3]. The examples of its scientific applications include but are not limited to X-ray absorption/emission spectroscopy (XAS/XES), hard X-ray high resolution single-shot spectrometry (HiREX), photon beam diagnostics, as well as veto generation for pixel detectors. The Gotthard-II detector can be operated in three different modes: 1) In burst mode, it is capable of taking images at 4.5 MHz and storing all the 2700 images from a bunch train of the EuXFEL on the readout ASIC and then sending them out during the bunch train spacing. 2) In continuous mode, it continuously takes and sends images at a frame rate of < 410 kHz without a stop, which extends its usage to synchrotron radiation sources and FELs in CW operation. 3) In counting mode, it counts the photon hits above a given threshold for all strip channels continuously at a frame rate of max. 4.5 MHz, which enables observing reactions or processes with a long transition period and a good time resolution of hundreds of nanosecond. In the flash talk, the architecture, features and applications of the Gotthard-II detector will be introduced.

[1] J. Zhang et al., *Design and first tests of the Gotthard-II readout ASIC for the European X-ray Free-Electron Laser*, J. Instrum. (2021).

[2] W. Decking et al., *A MHz-repetition-rate hard X-ray free-electron laser driven by a superconducting linear accelerator*, Nat. Photonics 14, 391-397 (2020).

[3] T. Tschentscher et al., *Photon Beam Transport and Scientific Instruments at the European XFEL*, Appl. Sci. 2017, 7(6), 592 (2017).

XIDER: a novel X-ray detector for the next generation of high-energy synchrotron radiation sources

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Abstract:

Next-generation sources of synchrotron radiation such as at the ESRF Extremely Brilliant Source (EBS), the first fourth-generation high-energy synchrotron facility worldwide, pose significant challenges for 2D pixelated X-ray detectors. In particular, scattering and diffraction experiments require fast detectors with a high dynamic range, from single photon sensitivity to pile-up conditions under very high photon fluxes.

The XIDER project aims to fulfil the needs of the above-mentioned high energy applications by implementing a novel incremental digital integration readout scheme [1]. XIDER detectors seek to operate efficiently under the high-flux EBS beam of up to 100 keV photons, with a time resolution that can cope with near-continuous and pulsed beams. Simultaneously, non-constant leakage current contributions can be removed for noise-free single photon detection, resulting in a very high dynamic range.

This contribution will introduce the digital integration readout concept and current status of the XIDER project.

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[1] P. Fajardo et al., *Digital integration: a novel readout concept for XIDER, an X-ray detector for the next generation of synchrotron radiation sources*, JINST 15 C01040 (2020), doi: 10.1088/1748-0221/15/01/C01040.

Azimuthal integration for fast X-ray area detectors on FPGAs

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Abstract:

With recent advancements of high level synthesis (HLS) tools for programmable logic design more complex data processing and reduction code can be integrated on field programmable gate arrays (FPGAs) [1]. An implementation of azimuthal integration (AZINT) algorithm on FPGAs is presented. AZINT on FPGAs can be understood as a sort of binning or histogram calculation adjusted for specific case of synchrotron scattering and diffraction experiments. The first prototype [2] using Synchronous Message Exchange (SME) language demonstrates that data streams around 600 Gb/s can be processed with large boards (similar to used in [1]). The second implementation using OpenCL extends the application to floating point data processing, which allows to include physically relevant corrections and provide same output as complex algorithms used on CPUs or GPUs nowadays. The AZINT implementation on FPGAs would allow improvements to noise to signal ratio in certain type of fast feedback experiments. It can be also present as a component of other more complex data processing procedures.

[1] F. Leonarski et al., *Fast and accurate data collection for macromolecular crystallography using the JUNGFRAU detector*, Nature Methods 15, 799-804 (2018).

[2] C. Johnsen, SME Binning, https://github.com/bh107/SME-Binning (visited on Feb 27th, 2021).

Development of data acquisition and analysis infrastructure for high-speed X-ray imaging detector CITIUS

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Abstract:

Advances in accelerator technologies have made it possible to deliver electron beams with sub-100 pm rad emittance for high-brilliance X-rays. Some facilities utilizing the advanced accelerator technologies have started their operation and many others are under construction or proposed. At the proposed SPring-8-II facility [1], anticipated experiments require X-ray imaging detectors with a frame rate over 10 kHz, high pixel count, a count rate over 100 Mcps/pixel, and single-photon sensitivity. To meet these demands, we have been developing a high-speed X-ray imaging detector CITIUS (Charge Integration Type Imaging Unit with high-Speed extended-Dynamic-Range Detector) [2] for SPring-8 and SACLA. As for SPring-8, our first milestone is to install a 20M-pixel CITIUS detector in 2023. It has a frame rate of 17.4 kHz and a raw data rate of 1.4 TB/sec. Such a high raw data rate demands the careful design of the data handling scheme from the transfer, on-the-fly processing, storage, to post-analysis. Our baseline implementation is to reduce the peak data rate to 100 GB/sec by on-the-fly processing and further reduce it to 10 GB/sec by information-lossless compression. In this presentation, we describe our plan on the data acquisition and analysis infrastructure and the current status of the development.

[1] "SPring-8-II Conceptual Design Report" (Nov. 2014) http://rsc.riken.jp/eng/pdf/SPring-8-II.pdf.

[2] T. Hatsui, *New opportunities in photon science with high-speed X-ray imaging detector Citius, and associated data challenge*, Presentation at the 2nd R-CCS International Symposium (2020).

RASHPA: a generic RDMA-based distributed DAQ framework for high-throughput X-ray detectors

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European Synchrotron Radiation Facility

Abstract:

This talk will introduce RASHPA, an RDMA-based acquisition framework developed at the ESRF and undergoing final validation. In addition to implementing a highly parallelised architecture handling multi-GByte/s data transfers into a network of distributed processing nodes, RASHPA has been designed with the following three main objectives:

Assist data management and processing – In addition to high-throughput zero-copy data transfer (RDMA based) from the detector into the destination memory buffers (system RAM, GPU or FPGA memory), RASHPA provides features to facilitate data management and low-latency processing such as simultaneous data streams and image operations.

Scalability, wide range of implementations – A RASHPA implementation for a given detector can be rescaled and adapted for any final experimental need by reconfiguration of the topology and the data dispatching rules without any hardware or software development.

Standardisation and reusability – suitable to be used with a variety of detector systems and over a long-lasting period of time, reducing future development efforts. RASHPA is not restricted to a specific physical data link or protocol, as long as it supports RDMA, and it relies on commercial-off-the-self components for the backend computing nodes.

The first fully RASHPA qualified detector is SMARTPIX, a Medipix3-based modular detector built in several form factors with two variants using PCIe and RoCEv2 (RDMA over Converged Ethernet) for data transfer. The RoCEv2 implementation uses a single 100 GbE link for each half a megapixel module and the largest detector built so far is a 1M system with, 25 GB/s of aggregated bandwidth, sufficient to cope with more than three times the maximum throughput produced by the front-end of the detector at the maximum speed of 3000 fps. Such "excess" of bandwidth allows taking advantage of RASPHA to send the full image data or subsets of them simultaneously to different destinations. In that way it is possible for instance to dedicate separate independent computing resources to different operations either if they are computing intensive (data compression and storage or very fast on-line data processing), or not (e.g. data visualisation or monitoring).

The management of such a functionally complex system operating across a network of distributed computing nodes is not trivial. That is why RASHPA is complemented by LIMA2, a distributed version of LIMA, the ESRF standard detector control and data acquisition software, also under advanced stage of development.

Development status of new readout system for SOI pixel detector using 10 Gb Ethernet SiTCP

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Abstract:

The SOI (Silicon-On-Insulator) pixel detector is the monolithic imaging device developed by the SOIPIX group led by KEK [1]. This detector is being tested for practical use such as X-ray imaging and X-ray residual stress measurement, but the readout FPGA (Field-Programmable Gate Array) board SEABAS2 (Soi EvAluation BoArd with SiTCP [2] version 2), which is mainly used for the readout of this detector is becoming obsolete. This has led to problems such as insufficient readout speed, restrictions on the implementation of advanced processing due to the insufficient circuit scale of the FPGA. Therefore, in order to solve these problems and improve overall performance and usability, we are developing the new readout board with newer generation FPGA and 10 GbE SiTCP (10 Gigabit Ethernet network processor library logic circuit running on FPGA). Prior to the development of new board, we constructed a prototype system using the FPGA evaluation board KC705 to evaluate the 10 GbE SiTCP. In November 2020, as a part of evaluation, this prototype system was tested at KEK PF BL-14A and BL-14B, with the SOI pixel detector named INTPIX4NA. In this test, we confirmed the relaxation of the frame rate limit and the improvement of the frame rate stability due to the improvement of the readout speed.

[1] Y.Arai et al., *Development of SOI pixel process technology*, Nucl. Instrum. Methods Phys. Res. A 636, S31-S36 (2011).

[2] T. Uchida, *Hardware-based TCP processor for gigabit Ethernet*, IEEE Trans. Nucl. Sci. NS-55 (3), 1631–1637 (2008).

Event driven readout system with non-priority arbitration for radiation detectors

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Abstract:

A new readout architecture for radiation detectors is presented. It incorporates, inter alia, an asynchronous arbitration tree based on Seitz' arbiters [1], thanks to which the imposed prioritization, known from prior art [2], was eliminated in favor of arbitration with memory elements. This solution additionally protects against switching to other channels during the readout procedure and gets rid of the need to create a snapshot of the states of channels prior to the arbitration [3]. Equally novel is the in-channel logic structure that allows dividing the entire readout transaction into multiple phases. This gives the possibility of configuring the number of readout phases as needed for systems where charge sharing occurs and neighbor pixels have to be read out. Another advantage of the presented system is the simplification of the entire readout scheme: it is controlled by a single edge of the clock signal sent into the arbitration tree[4]; the system works at any clock's duty cycle.. There is no dead time either. These features are related to the method of synchronization with the external acquisition system. The synchronization takes place seamlessly on the global logic side, without direct distribution of the clock signal to each of the channels resulting allowing power savings. The presented system also has a mechanism for detecting the condition of no-channel request: data with an empty pattern is sent automatically to keep the synchronization with the data acquisition system. The described architecture is developed, for multichannel radiation detectors, particularly pixels detectors, where data sparsification is required, and can also be used to read out channels one by one in the so-called imaging mode.

[1] Y. Zhang, L. S. Heck, M. T. Moreira, D. Zar, M. Breuer, N. L. V. Calazans and P. A. Beerel, *Design and Analysis of Testable Mutual Exclusion Elements*, in 2015 21st IEEE International Symposium on Asynchronous Circuits and Systems, 2015.

[2] P. Yang, G. Aglieri, C. Cavicchioli, P. L. Chalmet, N. Chanlek, A. Collu, C. Gao, H. Hillemanns, A. Junique, M. Kofarago, M. Keil, T. Kugathasan, D. Kim, J. Kim, A. Lattuca, C. A. M. Tobon, D. Marras, M. Mager, P. Martinengo, G. Mazza, H. Mugnier, L. Musa, C. Puggioni, J. Rousset, F. Reidt, P. Riedler, W. Snoeys, S. Siddhanta, G. Usai, J. W. van Hoorne and J. Yi, *Low-power priority Address-Encoder and Reset-Decoder data-driven readout for Monolithic Active Pixel Sensors for tracker system,* Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 785, pp. 61-69, 2015.

[3] G. W. Deptuch, G. Carini, P. Gryboś, P. Kmon, P. Maj, M. Trimpl, D. P. Siddons, R. Szczygieł and R. Yarema, *Design and Tests of the Vertically Integrated Photon Imaging Chip*, IEEE Transactions on Nuclear Science, vol. 61, pp. 663-674, 2014.

[4] F. Fahim, S. Joshi, S. Ogrenci-Memik and H. Mohseni, *A Low-Power, High-Speed Readout for Pixel Detectors Based on an Arbitration Tree*, IEEE Transactions on Very Large Scale Integration (VLSI) Systems, vol. 28, pp. 576-584, 2020.

Application of TES spectrometers in advanced x-ray spectroscopy at SSRL

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Abstract:

TES spectrometers can provide unique combination of high energy resolution (~ 1.5 eV) and high collection efficiency in a broad range of x-ray energies. We commissioned two TES spectrometers and have been operating them under the general user program at SSRL BL 10-1 [1] and BL 13-3. So far, the most frequent use of these TESs has been measuring soft x-ray absorption spectroscopy (XAS) spectra of materials in the partial fluorescence yield (PFY) mode. However, the PFY-XAS does not fully utilize the capability of the TESs in that it does not require particularly high energy resolution. In this flash talk, we will present our efforts to apply the TES spectrometers in advanced x-ray spectroscopy that benefits from all three key characteristics of the TES (high energy resolution, high efficiency, and broadband) as well as those of their host endstations. More specifically, the BL 10-1's high throughput set-up can enable material characterization through RIXS fingerprints, and BL 13-3's EPU (elliptically polarizing unit) can enable novel RIXS-MCD (magnetic circular dichroism). We will conclude with a discussion on directions for a new TES spectrometer for synchrotron-based advanced soft x-ray spectroscopy.

[1] S.-J. Lee et al., *Soft X-ray spectroscopy with transition-edge sensors at Stanford Synchrotron Radiation Lightsource beamline 10-1*, Rev. Sci. Instrum. 90, 113101 (2019).

Soft X-ray transition edge sensor spectrometers at SSRL

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Abstract:

X-ray spectrometers based on cryogenic microcalorimeters such as Transition Edge Sensors (TES) offer a powerful combination of high x-ray detection efficiency and relatively high resolving power. We give a brief introduction to the working principles of TES x-ray spectrometers and give some examples of beamline science where microcalorimeters are particularly useful; these include resonant inelastic scattering and partial fluorescence yield x-ray absorption spectroscopy of low concentration samples and damage sensitive samples as well as resonant scattering. We will describe the expected capabilities of two TES soft x-ray spectrometers that are being upgraded this year, those at the SSRL 10-1 and SSRL 13-3.

Simulation of the signal response of x-ray spectroscopy detectors

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Abstract:

A full-simulation chain of complex semiconductor detectors and its associated electronics is being developed by the Detector Group of SOLEIL synchrotron [1]. The simulation chain is based in two codes: Geant4 [2], a CERN C++ open-source to model the photon-matter interaction among all physics processes; and COMSOL Multiphysics, a license code to generate the 3D electric field map inside the semiconductor. The output data of these codes are integrated in Allpix2 simulation framework [3], which was initially developed for pixelated silicon detectors in High Energy Physics experiments. Several new features have been included to model the sample environment of a synchrotron experiment and the signal response of Silicon Drift Detectors (SDD) and germanium detectors equipped with a Digital Pulse Processor [4], commonly used in X-ray spectroscopy experiments. The whole simulation chain has been calibrated by experimental data from a XAFS experiment. As a first application, a study of the charge sharing and signal-to-background ratio of a multi-element germanium detector has been made. Simulation flow and this first study will be presented in this talk.

[1] T. Saleem et al., *Simulation of Multi-element Germanium Sensors for Synchrotron Radiation XAFS experiments using Allpix2 framework*, submitted to Nucl. Instrum. Meth. A.

[2] J. Allison et al., *Recent developments in Geant4*, Nucl. Instrum. Meth. A 835, 186-225 (2016).

[3] S. Spannagel et al., *Allpix2: A modular simulation for silicon detectors*, Nucl. Instr. Meth. A 910, 165-172 (2018).

[4] M. Bordessoule et al., *Performance of spectroscopy detectors and associated electronics measured at SOLEIL synchrotron*, AIP Conf. Proc. 2054, 060070 (2019).

(Very) quick EXAFS using the timestamp capabilities of Xspress4 DPP at Diamond Light Source

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Abstract:

Diamond Light Source (DLS) spectroscopy beam lines routinely uses Quick EXAFS techniques to gather sample data. Hundreds of individual MCA's are acquired per scan as the Monochromator continuously moves through the scan energy range, with individual time slice dwell times the order of 5ms. Development of brighter X-ray sources enables the use of Very Quick EXAFS scans for the same count statistics, but as time slices in the scan get smaller, variable latency in the event processing chain becomes problematic potentially leading to processed events being misallocated to the wrong MCA. DLS readouts out HPGe detectors using the Xspress4 Digital Pulse Processor [1]. Leveraging Xspress4's event timestamp capability, we present a method where event energy, channel ID and now time-of-arrival timestamp are output as an event list. Timestamps of two trigger signals from scan controlling electronics also record the scan start and predetermined Monochromator positions corresponding to specific energies in the scan. The event list is post processed to allocate events to the correct energy point based on their timestamps relative to Monochromator positions (energies) thus avoiding errors due to variable processing latency. Results will show that this method allows accurate event-to-energy allocation down to time slices as small as 50us. Further, as the raw event list is post processed, the user can choose to split the scan into multiple alternate time-slice positions, durations and granularity to better suit count statistics, potentially leading to higher quality EXAFS results.

[1] G.Dennis, W.Helsby, D.Omar, I.Horswell, N.Tartoni, S.Hayama, I.Mikulska and S.Diaz-Moreno, *First Results Using the New DLS Xspress4 Digital Pulse Processor with Monolithic Segmented HPGe Detectors on XAS Beamlines*, AIP Conference Proceedings 2054, 060065 (2019); doi: 10.1063/1.5084696.

The DSSC soft X-ray camera with Mega-frame readout capability for the European XFEL

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Abstract:

The DSSC camera [1] was developed for photon science applications in the energy range between 0.25 keV and 6 keV at the European XFEL [2] in the Hamburg area in Germany. The first complete 1-Megapixel DSSC camera is now available, fully tested and installed at the Spectroscopy and Coherent Scattering (SCS) instrument. The detector system is at the moment the fastest existing 2D camera for soft X-rays.

The camera is based on direct conversion Si-sensors and is composed of 1024×1024 pixels. 256 ASICs [4] provide full parallel readout, comprising analog filtering, digitization and in-pixel data storage. In order to cope with the demanding X-ray pulse time structure of the European XFEL, the DSSC provides a peak frame rate of 4.5 MHz. The first megapixel camera is equipped with Miniaturized Silicon Drift Detector (MiniSDD) pixel arrays. The intrinsic response of the pixels and the linear readout limit the dynamic range but allow one to achieve noise values of about 60 electrons r.m.s. at the highest frame rate.

The challenge of providing high-dynamic range (~104 photons/pixel/pulse) and single photon detection simultaneously requires a non-linear system front-end, which will be obtained with the DEPFET [4] active pixel technology foreseen for the advanced version of the camera. This technology will provide lower noise and a non-linear response at the sensor level.

We will present the architecture of the whole detector system with its key features. We will summarize the main experimental results obtained with the MiniSDD-based camera and give a short overview of the performed user experiments.

At the end we will shortly discuss the implementation of the second DEPFET-based camera with its main expected improvements in terms of noise and dynamic range.

[1] M. Porro et al., IEEE TNS, vol.59, no.6, pp.3339,3351, Dec. 2012.

[2] M. Altarelli et al., *European X-ray Free Electron Laser*, Technical Design Report, ISBN 978-3-935702-17-1 (2006).

[3] F. Erdinger et al., NSS Conference Record (NSS/MIC), 2012 IEEE, pp. 591–596.

[4] S. Aschauer, et al. Journal of Instrumentation, Volume 12, November 2017.

Calibration of a pnCCD detector at European XFEL

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Abstract:

A 450 μm-thick fully depleted, backside illuminated, 1-Megapixel pnCCD detector with a 1024 × 1024 pixel format (pixel size: 75 μm × 75 μm) has been installed and commissioned for imaging and spectroscopy applications at the Small Quantum System (SQS) instrument of the European X-ray Free Electron Laser facility [1]. The SQS instrument is operating at an energy range of 0.5 – 3 keV; however, the detector can handle photon energy range between 0.3 keV to 25 keV with quantum efficiency of 80% or higher for $0.7 \leq E_\gamma \leq 12$ keV. This detector enables single photon imaging due to its very low noise of 3e–. Our detector offers three operation modes with 7 gains per mode, which could be chosen per requirements for different experimental scenarios. These have been calibrated using flat-field illumination and an aluminum target for fluorescence imaging at 1.5 keV. My presentation focuses on a summary of the calibration and characterization results.

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[1] J. M. Kuster, et al., *1-Megapixel pnCCD detector for the Small Quantum Systems instrument at the European XFEL: system and operation aspects*, Journal of Synchrotron Radiation, Volume 28, Part 2 (2021) pages 576 – 587.

The Percival 2-Megapixel soft X-ray system in first user experiments

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[3] Science and Technology Faculties (STFC), Rutherford Appleton Laboratory (RAL), Didcot, United Kingdom
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[5] University of Saskatchewan, Saskatoon, Saskatchewan, Canada
[6] Diamond Light Source (DLS), Didcot, United Kingdom
[7] Pohang Accelerator Laboratory (PAL), Pohang, Gyeongbuk, Republic of Korea
[8] SOLEIL Synchrotron, Saint Aubin, France
[9] Max-Born-Institut Forschungsverbund Berlin e.V., Berlin, Germany
[10] Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany
[11] Mid Sweden University, Sundsvall, Sweden

Abstract:

The PERCIVAL imager has been developed by an international collaboration of light sources to provide an unprecedented combination of uninterrupted imaging area, large dynamic range spanning single-photon-discrimination at 250eV to multi-Me--signals, and high frame rates in the soft X-ray regime.

Based on a backside-illuminated CMOS imager, today's system offers 1408x1484 pixels of 27x27µm each, running at 83 Hz and spanning a dynamic range limited by electronic noise (16-25e- depending on operating conditions) at one end and a maximum signal of 3.6Me- per pixel at the other, or from ~0.25 to ~50000 photons at 250eV. Further improvements in both frame rate (design limit: 300 Hz) and noise are expected with continuing fine-tuning of the system.

In July and December 2020 we performed first user experiments with this system. At the Petra III storage ring's soft X-ray beamline P04 we explored holographic imaging of topological materials (in particular skyrmions) at an energy of 780 eV together with groups from Helmholtz Zentrum Berlin (HZB) and the Max-Born Institute (MBI). At FLASH2's F24 beamline, together with colleagues from FLASH we took ptychographic imaging data of plasma treated surfaces at an energy range between 92 eV and 462 eV. Both experiments benefitted from the large dynamic range provided by the system.

The JUNGFRAU as imaging detector for SwissFEL low energy beamline

A. Mozzanica, M. Andrä, R. Barten, A. Bergamaschi, M. Brückner, S. Chiriotti, R. Dinapoli, E. Fröjdh, D. Greiffenberg, T. King, C. Lopez-Cuenca, D. Meister, D. Mezza, C. Ruder, B. Schmitt, D. Thattil, S. Vetter and J. Zhang

Photon Science Detector Group, Paul Scherrer Institut, Forschungsstrasse 111, 5232 Villigen PSI, Switzerland.

Abstract:

The JUNGFRAU detector is in operation at the SwissFEL ARAMIS high energy beamline since 2017, with a total of more than 80 modules deployed in 13 different camera systems.

ATHOS, the low energy branch of SwissFEL, is entering now commissioning phase, with user operation scheduled to start later this year. The Maloja endstation will deploy an in vacuum JUNGFRAU 4M camera as large area detector for diffractive imaging experiments in the energy range 250eV-2keV.

The detector will be based on the modified 1.1 JUNGFRAU ASIC, providing improved linearity and noise performances, coupled with thin entrance window sensors, with enhanced Q.E. at low energy, developed in collaboration with FBK. Single photon resolution at energies higher than 600-700eV is expected, while keeping the high dynamic range capability of the original chip. The detector will be installed at the beamline in the first half of March.

The talk will present the design of the detector and preliminary results of the beamline commissioning.

Development of a 200-nm-resolution X-ray imaging detector with a field of view of 2 mm square

Takashi Kameshima[1,2] and Takaki Hatsui[1,2]

[1] Japan Synchrotron Radiation Research Institute
[2] RIKEN SPring-8 Center

Abstract:

Recently, we succeeded in developing a transparent thin-film scintillator and demonstrated a lens-coupled X-ray imaging detector resolving 200 nm line-and-space patterns [1]. So far about 10 detector systems are deployed at SPring-8/SACLA mainly for the beam characterization. It has a field of view of 133 µm square. In order to apply this technique to wider range of applications such as X-ray CTs, we need to enlarge its field of view while keeping the spatial resolution. In this talk, we report an indirect detector resolving 200 nm line-and-space patterns with a field of view of 2 mm square. It was made possible by incorporating a 150 Mega-pixel image sensor and a dedicated imaging optics. The detector is to be implemented to a high resolution X-ray computed tomography beamline at SPring-8.

[1] T. Kameshima, A. Takeuchi, K. Uesugi, T. Kudo, Y. Kohmura, K. Tamasaku, K. Muramatsu, T. Yanagitani, M. Yabashi, and T. Hatsui, *Development of an X-ray imaging detector to resolve 200 nm line-and-space patterns by using transparent ceramics layers bonded by solid-state diffusion*, Opt. Lett. 44, 1403 (2019).

CMOS X-ray Strip Detector Development at NSRRC

Te-Hui Lee, Kuan-Li Yu and Chen-Wan Hsu and Jade Huang

National Synchrotron Radiation Research Center (NSRRC)

Abstract:

A CMOS X-ray detector prototype is developed at NSRRC. The detector is a combination of CMOS sensor with fiber optical plate and scintillator. The CMOS sensor is designed by NSRRC cooperator and manufactured by foundry in Taiwan. The 4T pinned diode is used and pixel size is 5 µm. The prototype contains 400x400 pixels with sensor area 2x2 mm2. The form factor provides the possibilities to integrate into larger area to fit different experimental requirements in the future. Fiber optical plate and scintillator will be fused with CMOS sensor by Acuri Technology Co., Ltd. The thickness of scintillator can be changed to fit different photon energy. The readout circuit and software will be developed by NSRRC. The final device will be tested with X-ray at NSRRC by the end of 2021.

[1] M. H. Jeong et al., *Development of a portable digital radiographic system based on FOP-coupled CMOS image sensor and its performance evaluation*, IEEE Symposium Conference Record Nuclear Science 2004, Rome, Italy, 2004, pp. 1604-1609 Vol. 3, doi: 10.1109/NSSMIC.2004.1462547.

[2] J. G. Rocha and Senentxu L-M., *Review on X-ray Detectors Based on Scintillators and CMOS Technology*. Recent Patents on Electrical Engineering 2011, 4, 000-000.

MYTHEN III: the new microstrip detector for powder diffraction

A. Bergamaschi, M. Andrä, R. Barten, M. Brückner, S. Chiriotti, R. Dinapoli, E. Fröjdh, D. Greiffenberg, T. King, C. Lopez-Cuenca, D. Meister, D. Mezza, A. Mozzanica, C. Ruder, B. Schmitt, D. Thattil, S. Vetter and J. Zhang

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Abstract:

After more than 12 years of users operation, the MYTHEN II single photon counting microstrip detector has been upgraded in order to cope with progresses in the detector and data acquisition technology. MYTHEN III presents the same geometry as its predecessor (50 µm pitch 8 mm long strips, 6.4 mm wide modules), but it provides enhanced performance.

The new readout chip features improved noise down to 115 e- ENC and threshold dispersion of about 20 eV RMS [1]. The maximum frame rate is up to 300 kHz with no dead time between frames, and the count rate capability can reach up to 3.5 MHz per strip with 90% counting efficiency. Moreover, it is possible to exploit the three counters per strip with independent threshold and gate for not only energy binning and time resolved pump-probe applications, but also to push the count rate capability to above 20 MHz per strip with 90% efficiency, thanks to the possibility of counting piled-up photons [2].

Finally, we implemented an innovative digital intercommunication logic between channels, which allows improving the spatial resolution beyond the strip pitch, as a first demonstration of on-chip interpolation in a single photon counter detector.

A 48 modules MYTHEN III detector is under commissioning and the first 12 modules recently started users operation at the powder diffraction end station of the Swiss Light Source.

[1] Andrä M, *The MYTHEN III Detector System - A single photon-counting microstrip detector for powder diffraction experiments*, DISS. ETH NO. 27290, doi: 10.3929/ethz-b-000462676.

[2] Andrä M, et al. Journal of Instrumentation. 2019, 14(11): C11028. doi: 10.1088/1748-0221/14/11/C11028.

TimePix4, a versatile timestamping pixel detector

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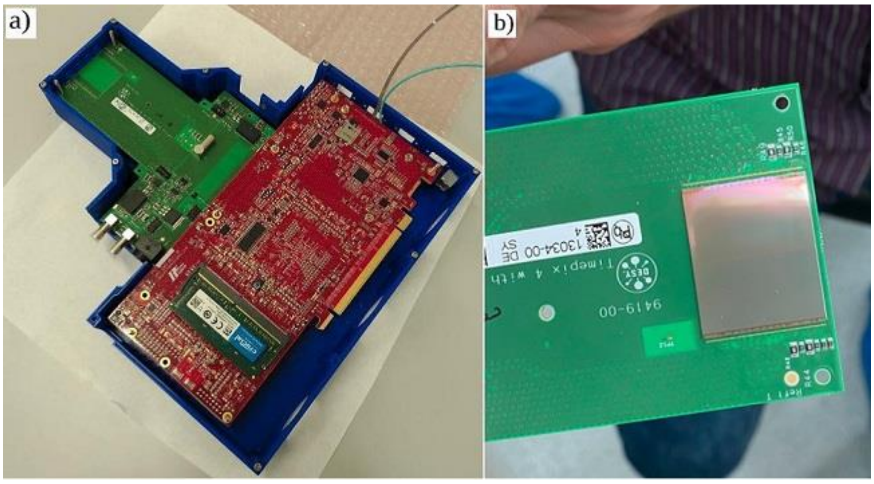
Abstract:

Timepix4 is a versatile readout chip with 55 µm pixels, developed by CERN on behalf of the Medipix4 collaboration. It can offer two distinct operation modes. Firstly, it operates in a photon counting mode, with a 10 times higher count rate capability than the Medipix3 readout chip used in detectors like LAMBDA, and a 40 kHz frame rate. Secondly, like its predecessor Timepix3, it can operate in an event-by-event mode: for each photon hit, the hit time is recorded with ns time resolution (sensor dependent) and the energy with ~2 keV resolution. In this mode, the chip can process approximately 1.8e8 hits/cm2/s. This would allow time-resolved experiments with single-bunch time resolution.

At DESY, the present development of a new readout system able to cope with the expanded readout bandwidth of up to 162 Gbps per chip is well on its way. The first step was the design, production and test of a single chip carrier board (Figure b). The layout, flat and with the chip at the edge of the board, enables a number of experimental set-ups, and also allows for 2-chip tiled systems. For this first iteration, a commercially available readout board (Figure a) hosting a powerful Zynq UltraScale+ System on Chip, has been chosen due the large number of high speed transceivers available.

In the long term, and in a similar way to what has been done with MediPix3-based systems, multichip multi-module systems are to be developed. New detector head boards and also custom readout boards will be needed. Furthermore, recent developments on Through Silicon Vias (TSV) technology will allow the chip to be fully powered, controlled and readout from the back, removing the constraint of wire-bonds and therefore, allowing full 4-side buttable systems.

a) TimePix4 single-chip carrier board and readout board; b) TimePix4 chip glued onto a single chip carrier board.



SPHIRD: small pixel, high rate photon counting detector for synchrotron applications

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Abstract:

The ongoing upgrade of synchrotron sources all over the world started few years ago and heading towards higher brilliance and much more coherent beams will boost the application of scattering techniques such as coherent diffraction imaging, X-ray photon correlation spectroscopy and ptychography. This scenario tightens the requirements on space, dynamic range and readout speed for the new generation of 2D detectors.

SPHIRD is a photon-counting, hybrid pixel detector project under study by ESRF and the AGH University of Science and Technology to address these concerns. The main goal is to optimize the combined detection performance in terms of count rate capability and spatial resolution to provide a unique detector for coherent scattering and other applications with not too different detection requirements such as ultra-SAXS or medium resolution in-vivo (low-dose) imaging. The project, that also targets medium hard X-ray energies up to 30keV, will take advantage of the deep sub-micrometer 40 nm CMOS technology to reduce the pixel size and improve the speed performance of the front-end electronics [1]. It will also implement advanced methods to compensate pileup at photon high rates, to reduce the photon losses due to charge sharing and to investigate the potential increase of spatial resolution below the pixel pitch [2]. The intention, once the initial R&D phase is completed, is to engineer and build a new generation of photon counting 2D detector that will surpass the capabilities of the current standard state-of-the-art by between one and two orders of magnitude, a substantial step that is absolutely necessary for the proper exploitation of the capabilities of the 4th generation of storage rings such as ESRF-EBS. In addition to high performance, SPHIRD will be conceived to be particularly flexible and versatile, allowing the users to enhance the most desired features of the detector according to the application needs.

[1] R. Kleczek, P. Grybos, R. Szczygiel, P. Maj, *Single Photon-Counting Pixel Readout Chip Operating up to 1.2 Gcps/mm^2 for Digital X-ray Imaging Systems*, IEEE J. Solid-State Circuits v.53, n.9, 2651-2662 (2018), doi: 10.1109/JSSC.2018.2851234.

[2] T. Johng-ay, P. Fajardo, T. Martin, C. Ponchut, P.A. Douissard, M. Ruat, *DECIMO: a Simulation Tool to Explore Next Generation of Detectors for Synchrotron Radiation Applications*, Proceedings of 2016 IEEE NSS/MIC/RTSD, doi: 10.1109/NSSMIC.2016.8069944

Development of thermoelectric cooling system for the PERCIVAL detector

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Abstract:

Pixelated Energy Resolving CMOS Imager, Versatile and Large (PERCIVAL) is a soft X-ray detector under development as a collaboration of photon science institutions namely, DESY, STFC, Elettra, DLS and PAL [1]. SOLEIL joined the consortium in 2019. The PERCIVAL is intended for direct detection of X-ray in the energy range 250 eV to 1 keV with high efficiency. It consists of 1408 × 1484 pixels with each pixel having a size of 27 µm. The target dynamic range is $1 \sim 10^5$ photons/pixel at 250 eV photon energy, and the noise should be less than 15 e^-rms to have single photon counting capability. Therefore, the detector should be cooled down to <−20℃, and a cooling system is required. A gas-based cooling method has been used for small-size prototype and the full-scale sensor at DESY. While the cooling system has a good efficiency, a rigid and large heat exchanger should be assembled, and flexibility and compactness are too low. To overcome these limitations, a thermoelectric cooling system based on the Peltier effect [2] is developed for the PERCIVAL. During the detector operation, about 10 W will be generated from the sensor and heat from the power board will be transferred to the sensor. There are molybdenum and copper blocks between the sensor and the thermoelectric element. Thus the cooling system should overcome above 10 W active and passive heat loads. The detector head can be extended from 2M-pixels to 8M-pixels as a cloverleaf assembly. To keep it, the area of the thermoelectric element should not be larger than the area of the copper, 50 mm × 42 mm. In this presentation, we present about the developed thermoelectric cooling system for the PERCIVAL detector.

[1] C. B. Wunderer, et al., *The PERCIVAL soft X-ray imager*, J. Instrum. 14, C01006 (2019).

[2] T. M. Tritt, *Thermoelectric Materials: Principles, Structure, Properties, and Applications*, Encyclopedia of Materials: Science and Technology (Second Edition), 1-11 (2002).

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Fast MCP/Timepix photon counting detectors with high spatial and timing resolution

A.S. Tremsin on behalf of SSL/LBL collaboration

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Abstract:

The count rate capabilities and spatial resolution of event counting detectors with Microchannel Plates (MCPs) recently were improved by adapting Medipix technology as a readout placed directly below the MCPs. In those devices, the incoming particles (photons, electrons, neutrons, atoms, ions) converted into an output charge of 10^4-10^5 electrons are collected by the pixelated Medipix/Timepix readout enabling simultaneous detection of multiple particles at the MCP gains substantially lower compared to other event counting readouts. The signal multiplication by MCPs and Timepix thresholding enable operation of those detectors at virtually zero readout noise. The fast Timepix readout extends the capabilities of MCP detectors to GHz rates, allowing detection of multiple simultaneous events with spatial and timing resolution as good as ~10 µm and <2 ns, respectively, for the existing Timepix3 readout and possibly down to ~200 ps with next generation Timepix4 readout. In this talk, we will discuss the status of this detection technology and discuss several applications of those devices and the near-future developments

[1] A.S. Tremsin, J.V. Vallerga, *Unique capabilities and applications of Microchannel Plates detectors with Medipix/Timepix readout*, Radiation Measurements 130 (2020) 106228.

[2] A.S. Tremsin, J.V. Vallerga, O.H.W. Siegmund, *Overview of spatial and timing resolution of event counting detectors with Microchannel Plates*, Nuclear Instruments and Methods in Physics Research A 949 (2020) 162768.

[3] A.S. Tremsin, J.V. Vallerga, R.R Raffanti, *Optimization of spatial resolution and detection efficiency for photon/electron/neutron/ion counting detectors with Microchannel Plates and Quad Timepix readout*, Journal of Instrumentation JINST 13 (2018) C11005.

Investigation of HR GaAs:Cr material and X-ray pad sensors made of VGF n-GaAs wafers

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Abstract:

This paper presents the results of a study of the electrophysical characteristics of high-resistive gallium arsenide (VGF HR GaAs: Cr), as well as charge collection efficiencies and $(\mu\times\tau)_n$ values of pad sensors based on it. VGF HR GaAs: Cr wafers were fabricated by chromium compensation of 4 inches VGF n-GaAs wafers. Investigations of resistivity and photosensitivity distributions over the VGF HR GaAs: Cr wafer areas were done my means of non-contact methods. The study of the parameters of the dislocation cell network and large-scale defects was carried out by mapping the wafers in the SWIR range (1000-1200 nm). The $(\mu\times\tau)_n$ values value of pad sensors were estimated using the charge collection efficiency dependence on the bias voltage. The 60 keV gamma-quanta of ^{241}Am source were used.

It was found that the VGF n-GaAs material is characterized by the absence of “bubbles” defects along the entire length of the crystal, as well as by larger cell sizes (up to 1–2 mm) of the dislocation cell network as compared to LEC n-GaAs. It was shown that VGF HR GaAs: Cr material has $(\mu\times\tau)_n$ values about 5×10^{-5} cm^2/V.

High-Z detectors for photon science

Abdul K. Rumaiz

NSLS II Brookhaven National Laboratory

Abstract:

Sensors with high quantum efficiency for X-ray energies beyond 20 KeV are critical in addressing the scientific needs of synchrotron sources. Ge, has been widely semiconductor for hard X-ray radiation detection. High purity Ge offers excellent energy resolution, however the low bandgap of Ge requires cryogenic cooling to reduce thermally excited charge carriers. Alternately, materials such Cadmium Zinc Telluride, amorphous selenium offers the advantage of room temperature operation while maintaining good quantum efficiency for hard X-rays. In this flash talk I will present an overview of the current and past high-Z detector efforts at BNL.

Structured scintillators review

K. Pauwels and P.A. Douissard

ESRF, The European Synchrotron, Grenoble, France.

Abstract:

The indirect detection of X-rays based on scintillators is a well-established technique implemented on many synchrotron beamlines. Apart from their attractiveness in terms of cost, indirect detectors also offer a wide dynamic range, an excellent versatility and an easy adaptation to the beamline needs. For applications requiring optimizing both the spatial resolution and the X-ray absorption efficiency, the micro-structuration of scintillators offers the best compromise. We will review the existing technologies and compare their performances and limitations. In the context of the Extremely Brilliant Source (ESRF-EBS), a particular emphasis will be set on radiation resistance and afterglow at high X-ray doses.

Large-area, highly granular detectors for hard X-rays

G Pinaroli[1], G. Carini[1], A. Datta[2], K. Hansen[2], G. Deptuch[1], P. O’Connor[1], S. Motakef[2]

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[2] CapeSym Inc., 6 Huron Drive, Natick, 01760, MA

Abstract:

Applications in the medical, scientific, and industrial inspection fields have a wide and growing need for X-ray imaging detectors for higher energies of X-rays. Such devices, typically, consist of light-sensitive active-matrix arrays coupled to an X-ray scintillator with a pixel pitch of 50-µm or larger [1]. A smaller pixel size is desirable for higher spatial resolution, but it is challenging because of the tradeoff between the scintillator’s X-ray absorption properties and spatial resolution. Another configuration is direct conversion of X-rays into charge by employing thick semiconductor films with an applied bias that yields both high X-ray absorption and high spatial resolution. Using direct-conversion, typically smaller pixel sizes (down to 10 to 5 um) are achievable [2].

In this project, CapeSym and BNL aim to develop a hard X-ray imaging detector suitable for synchrotron applications using a novel material as radiation sensitive element. An ~1cm x 1cm CMOS MAPS will be designed with a small pixel size (~5 to 10 µm) and coupled with a thin layer of MAPBI3 perovskite material which enables low-dose X-ray imaging in the energy regime up to 100 keV [3,4]. This presentation outlines different challenges, from the design of the CMOS MAPS device due to the small pixel size and a large count of pixels (~2 Mpixel), to the deposition of the MAPBI3 on the chip surface and its functionalization.

[1] R. A. Lujan and R. A. Street, *Flexible X-ray detector array fabricated with oxide thin-film transistors*, IEEE Electron Device Letters, vol. 33, no. 5, pp. 688–690, May 2012.

[2] A. Parsafar, C. C. Scott, A. El-Falou, P. M. Levine and K. S. Karim, *Direct-Conversion CMOS X-Ray Imager With 5.6 um x 6.25 um Pixels,* in IEEE Electron Device Letters, vol. 36, no. 5, pp. 481-483, May 2015, doi: 10.1109/LED.2015.2410304.

[3] A. Datta, Z. Zhong, S. Motakef, *A new generation of direct X-ray detectors for medical and synchrotron imaging applications*, Scientific Reports 10, 20097 (2020). doi: 10.1038/s41598-020-76647-5.

[4] Kim, Y., Kim, K., Son, DY. et al. Printable organometallic perovskite enables large-area, low-dose X-ray imaging. Nature 550, 87–91 (2017). doi: 10.1038/nature24032.

Large area silicon sensors in advanced CMOS process

Tomasz Hemperek

University of Bonn

Abstract:

Upgrades of present and future High-Energy Physics experiments require large radiation tolerance and small-pitch silicon-based sensors.

An attractive option for the production of pixel sensors in such large area detectors is the use of a CMOS processing lines for fabrication. Apart from the cost-effectiveness and high-throughput of commercial CMOS lines, process features can be exploited to further enhance the sensor performance. For example, MIM-capacitors and poly-silicon resistors allow for AC coupling and multiple metal layers enable flexible routings.

After 5 years of R&D with passive CMOS sensors using the LFoundry 150 nm CMOS process, with many prototypes and design iterations, a milestone has now been reached. In a dedicated submission full-size sensor have been produced fulfilling LHC quality criteria.

This presentation will show design and measurement results, such as detection efficiency, break down behaviour, and charge collection properties. Possible benefits and applications for X-ray imagining will be demonstrated such as wafer scale homogeneous modules with the use of TSV or sub-pixel pitch sensors.

Switch performance measurement of junction field effect transistor integrated in pixel sensor

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[3] Dongnam Inst. of Radiological and Medical Science, Jwadong-gil 40, Jangan-eup, Gijang-gun, Busan 40633, Korea

Abstract:

Different types of X-ray silicon detectors have been developed for structural studies in protein crystallography which has typically about 12 keV X-ray energies. For X-ray energies of interest, the thickness of silicon material exceeding 400 µm is required for a good photon detection efficiency because the thickness of the active silicon should be at least twice the absorption length. The CMOS pixel sensor has shallow p-n junction depth so that it has poor sensitivity to X-ray energies of interest to crystallography. A high resistivity pixel sensor provides to use the thick silicon as an active volume by full depletion. The sensor uses direct conversion of X-ray in silicon and the number of charges produced is proportional to the incident X-rays. The cylindrical junction field effect transistor (JFET), which is intrinsically radiation hard, is employed as a switch after integration into the pixel sensor. The produced charges by photon conversions are stored in the front side of the pixel until transferring them to the drain of the JFET switch during the readout cycle. Once charges are transferred to the readout pad in a column connected to the same readout line, all pixels in the row are read out and the next row is then selected by the gate control voltage. We develop JFET integrated in the high resistivity n-type silicon pixel and present optimal fabrication conditions for effective switching performance of the JFET for various design parameters and fabrication conditions.

[1] W. Chen, G. De Geronimo, Z. Li, P.O'Connor, V. Radeka, P. Rehak, G.C. Smith, J.S. Wall, B. Yu, *High resistivity silicon active pixel sensors for recording data from STEM*, Nuclear Instruments and Methods in Physics Research A 512, 368-377 (2003).

[2] Hyeyoung Lee, Jin-A Jeon, Jinyong Kim, Hyunsu Lee, Moo Hyun Lee, Manwoo Lee, Seoungcheol Lee, Hwanbae Park and Sukjune Song, *Measurement of Switching Performance of Pixelated Silicon Sensor Integrated with Field Effect Transistor*, Sensors, 19, 5580 (2019).

Low-gain avalanche diodes for photon science

Gabriele Giacomini

Brookhaven National Laboratory

Abstract:

Low-Gain Avalanche Diodes (LGADs) are a class of silicon sensors developed within the High Energy Physics (HEP) community, particularly by the CERN RD50 collaboration[1], and used for fast tracking of mips. They feature a gain layer able to boost the signal by a factor of a few tens which makes such devices, which for HEP applications are built on thin substrates, very fast (tens of picoseconds). We are studying if these devices can be used in photon science for fast detection of X-rays, in fact a GHz event rate per channel is possible, and detection of soft X-rays, which can be over the threshold for detection, by exploiting the gain mechanism. We'll discuss how for low penetrating particles a type-reversal of the doping type is in order and how this has been accomplished at BNL. Another feature of the LGAD is that they do not allow for a fine spatial resolution: efforts to modify the basic concept are on-going to solve this severe drawback so as to develop a 4D detector having excellent spatial and timing resolution.

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[1] https://rd50.web.cern.ch